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Artificial Drying of Forage Crops[1]

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NEED FOR FORAGE DRIERS

Production and curing of forage crops are important farm operations in most parts of the United States. Not only is forage a basic ingredient of livestock rations but it also has a prominent place in crop rotation and in the conservation of soil fertility. Since it is desirable to bring high-quality production in line with profitable operation, attention is being given to the curing of forage artificially. This undertaking was stimulated by results of feeding experiments that showed high grade (U. S. grade) forage is usually superior in feeding value to low-grade forage.

Feeding experiments have demonstrated (p. 25) that with artificial drying, forage of superior quality can be obtained from a crop that otherwise, under unfavorable weather conditions, would be of inferior quality. Methods and equipment employed in harvesting, curing, and subsequent processing operations govern to a large degree the value of the product for feed. This is especially true in the more humid areas. Overdrying, leaf shattering, and discoloration by rain and dew reduce the returns to the grower regardless of whether the hay is used on the farm or is sold. At times unfavorable conditions result in virtually a total loss of the crop.

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[1] This refers to quick drying, for a period of less than 1 hour, often referred to as dehydration.

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The use of green, leafy alfalfa hay and of alfalfa meal as a source of vitamin A has also stimulated interest in artificial drying. When the crop is cut at the proper stage and dried artificially, hay or hay products equivalent to U. S. No. 1 Extra Green, Extra Leafy alfalfa may be obtained. The carotene content, source of vitamin A activity, usually is higher in artificially dried hay than in sun-cured hay of the same grade. Artificial drying also tends to preserve the protein and mineral elements of hay by eliminating the possibilities of leaf shattering in handling and of leaching caused by weathering in the field.

TYPES OF DRIERS

The artificial drying of forage crops has been practiced to a limited extent in some localities in the United States for many years. Available information does not indicate the exact date the first hay drier was used in this country, but about 1909 an experimental drier was constructed and used in Missouri for alfalfa, and a machine was constructed for drying native grasses in Louisiana as early as 1910. Since that date a number of types and designs of driers have been developed.

The design of many of the early machines indicated a radical departure from established practices in the utilization of heat to evaporate moisture from damp or wet materials. In other cases equipment typical of that used for drying materials other than hay was slightly altered or changed in design. The most common types were those generally known as apron-conveyor and revolving-drum driers. An apron-conveyor drier of the type commonly used for hay is diagrammatically illustrated in figure 1, and drum driers in figures 2 and 3.

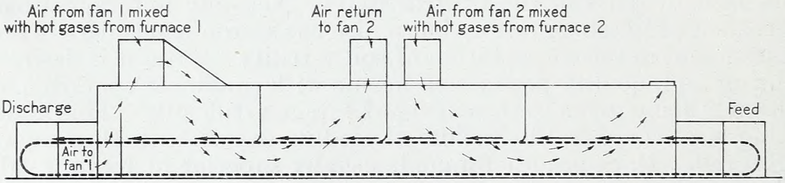
Air from fan 1 mixed with hot gases from furnace 1
Air return to fan 2
Air from fan 2 mixed with hot gases from furnace 2
Discharge
Feed
Air to fan 1

FIGURE 1.—Apron-conveyor type of forage drier.

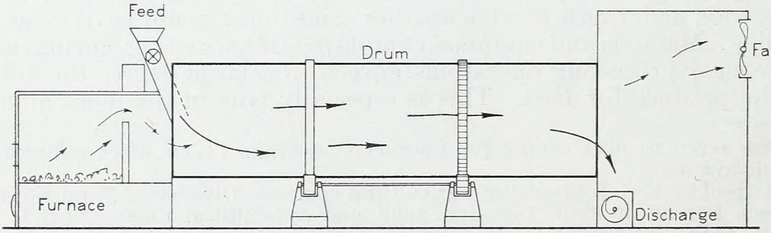

FIGURE 2.—Revolving-drum type of forage drier, single-drum design.

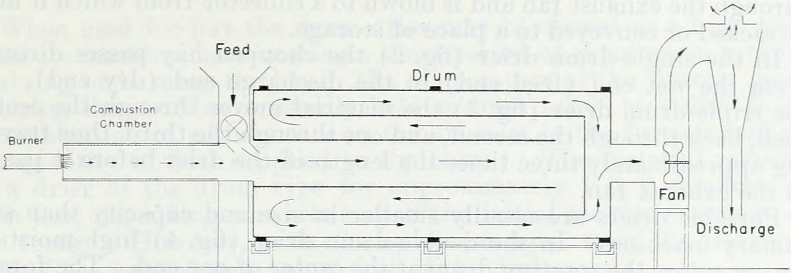

Figure 3.—Revolving-drum type of forage drier, triple-drum design.

The principles involved in these machines are not new, but the direct exposure of material to be dried to the furnace gases is a practice that has been closely associated with the development of hay driers of various types in the United States. Previously steam was commonly used, the material to be dried being brought into direct contact with or exposed to air heated by steam radiators. Higher efficiency in the utilization of heat and elimination of the expense and trouble commonly associated with steam boilers are factors frequently cited in favor of direct application of furnace gases.

In the apron-conveyor type (fig. 1) the green forage is loaded on an endless screen-wire apron and conveyed through the drying chamber where hot air or furnace gases are circulated through the layer of forage on the apron by means of one or more fans. Driers of this type may have a single endless conveyor, or several conveyors one above the other. As the drying air becomes saturated with moisture it is drawn or allowed to escape from the machine into the atmosphere. Apron-conveyor driers are not adapted to handling finely chopped forage, especially the single-apron machines, because the apron screen allows a considerable portion of the material to drop through, and the chopped hay, unless it is placed in a comparatively thin layer, forms a mattress practically impervious to the passage of the drying gases. However, crushing the forage by running it through a device patterned after a clothes wringer and cracking the stems, especially the nodes, is found to be of appreciable assistance in drying the forage.

Drum driers of the single-drum type (fig. 2), used for drying granular substances such as salt, have the feed end slightly elevated. As the drum revolves the material is picked up by baffles or flights fastened to the inside of the shell and then allowed to fall. Each time some of the material is picked up it falls somewhat closer to the discharge end because of the sloping position of the drum. In drying hay, the drum is placed in a horizontal position and a current of heated air, or furnace gases, is relied upon both for drying and for moving the forage through the machine. The design of the baffles also influences the movement of forage through the driers. When using drum driers it is necessary to chop the forage before it is fed into the machine. In some driers of this type the dry material is drawn into a chamber at the discharge end, from which it is conveyed mechanically to a storage structure. In most cases, however, the dry hay passes through the exhaust fan and is blown to a collector from which it may be sacked or conveyed to a place of storage.

In the single-drum drier (fig. 2) the chopped hay passes directly from the wet end (feed end) to the discharge end (dry end). In the triple-drum drier (fig. 3) the material moves through the center shell, back through the second, and out through the third, thus traveling approximately three times the length of the drier before it passes to the exhaust fan.

Portable driers are usually smaller in size and capacity than stationary machines. In the double-drum drier (fig. 4) high-moisture forage enters the rotating drum at the center of one end. The forage moves down the center and back through the outer drum. The forage is passed from the drying-drum through two cyclones for cooling. The action of the drying-air through the drum aided by the baffles or flights in the drum moves the forage through the drier. The exposure of the forage to the drying-air is less than one half the distance of travel of that in the stationary drums.

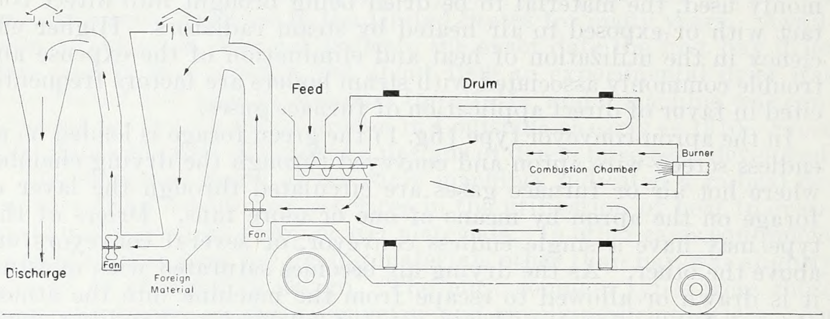

FIGURE 4.—Revolving-drum type portable forage drier, double-drum design.

The apron-conveyor drier is a relatively low-temperature drier in which the material remains for a considerable period of time. The temperature of the drying air or furnace gases entering the machine is usually held at from 250° to 350° F., and the period of exposure may vary from 15 to 45 minutes, depending in part upon the initial moisture content of the forage. The temperature of the hay remains much lower than that of the surrounding gases because of the cooling effect of evaporation. The temperature of the forage also tends to coincide with the wet-bulb temperature of the drying air, which, in a hay drier, is much below the dry-bulb temperature.

Apron-conveyor driers are usually much larger machines than drum driers, partly because of the longer period of exposure required. Single apron-conveyor driers for hay are frequently 150 to 200 feet long, 10 feet wide, and 10 feet high.

Drying the forage without chopping, or chopping it in long pieces, also tends to increase the time during which the material must remain in the machine. The leafy portions and fine stems dry quickly, whereas considerable time is required for drying the long, coarse stems. The overdrying of some parts of the plant and heat losses from the long tunnel may result in a low thermal efficiency for some machines of the apron-conveyor type.

When used for hay the drum drier may be classed as a high temperature machine, necessitating a short period of exposure to prevent charring or burning the hay. The temperature of the furnace gases entering the machine is usually held at from 1,000° to 1,500° F. by a combination of adjustments on the air inlet to the furnace and on the quantity of fuel supplied to the burner. The material remains in a drier of the drum type for approximately 1 to 3 minutes, or even less, depending somewhat upon the initial moisture content of the forage. However, as in the apron-conveyor type, the temperature of the hay is much below that of the drying gases.

The chopping of the hay into short pieces enables it to dry quickly and thereby makes possible the use of high temperatures in drum driers. The use of air for moving the material through the drier is helpful in preventing overdrying, since the light particles move more rapidly than the stemmy material.

The use of high temperatures and a short period of exposure in drum driers makes possible a rather small, compact unit in comparison with the apron-conveyor type. Single-drum driers are usually 35 to 40 feet in length and from 7 to 10 feet in diameter. Double- or triple-drum driers may be somewhat shorter than single-drum units, as the use of multiple drums increases the length of the drying zone with reference to over-all length.

In drum driers there seems to be a definite relation between the temperature of the exhaust gases and the moisture content of the hay as it is discharged from the machine. An exhaust-gas temperature of about 225° to 325° F. is usually maintained by controlling the rate of feed of undried hay. If the moisture content of the forage entering the drier is high (65 to 80 percent) the exhaust temperature should be kept at the high point of the range. When moisture content is around 50 percent the exhaust temperature should be held at the lower end of the range. The high exhaust temperature represents a considerable loss of heat that tends to reduce the thermal efficiency of drum driers.

TESTS OF DRIERS

Early investigational work by the United States Department of Agriculture consisted of a study of the mechanics of artificial drying of forage crops, the elements of cost, and the feeding value of artificially dried forage. Work of this type was done by the Department as early as 1930. A small apron-conveyor drier of the type commonly used in drying cotton linters was set up on the Iberia Livestock Experiment Station at Jeanerette, La., for experimental use in drying crops for feeding trials (fig. 5). This machine was approximately 46 feet long, 11 feet wide, and 9 feet high. The drying chamber was approximately 8 by 36 feet, and the machine would usually evaporate from 500 to 1,000 pounds of water per hour under the conditions in which it was operated. This drier was used for several seasons, but its capacity was insufficient for drying the forage needed for feeding trials. It was unsatisfactory also for drying coarse-stemmed crops such as soybeans.

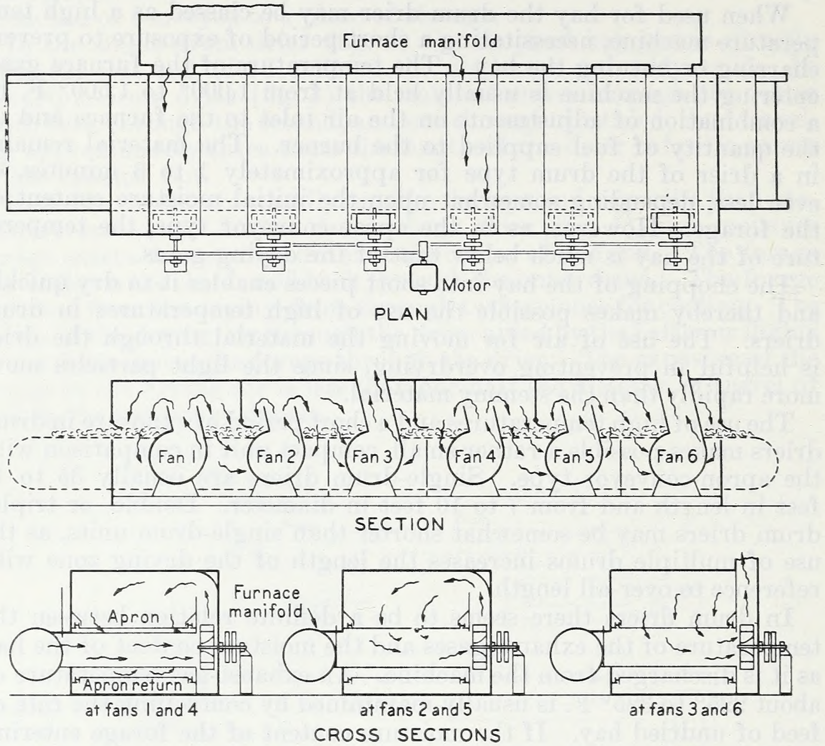

Figure 5.—Apron-conveyor drier used in forage-drying experiments at Iberia Livestock Experiment Station. Drying air enters fan 1 from furnace manifold and is discharged above apron, is drawn through apron by fan 2 and released above it in second compartment, and then is drawn again through apron by fan 3 and released outside the drier. Circulation through fans 4, 5, and 6 is similar.

In all the experimental driers at Jeanerette discussed herein, electric power was used for operating the machinery and fuel oil was used for heat, because of the ease of measuring the quantities used and ease of control.

After the conveyor-type drier had been used for a few years, a revolving-drum drier was installed. This machine consisted of a single shell 6 feet in diameter and 24 feet in length, mounted horizontally. Flights or flanges were attached to the inside of the shell, for picking up and dropping the chopped forage as the drum revolved. A furnace was connected to one end of the drum and an exhaust fan to the other. The dried forage passed from the drum through the fan and was blown into a cyclone. This machine was inefficient because of the short drying zone, or length of travel, and period of exposure of the material in the drier.

In order to increase the efficiency of this machine a cylinder 2 feet in diameter and 20 feet long was installed inside and concentrical with the large drum (fig. 6). This cylinder was connected to the furnace and to the feeder for the undried material at the furnace end of the drier. At the opposite end the 2-foot cylinder was open and ended

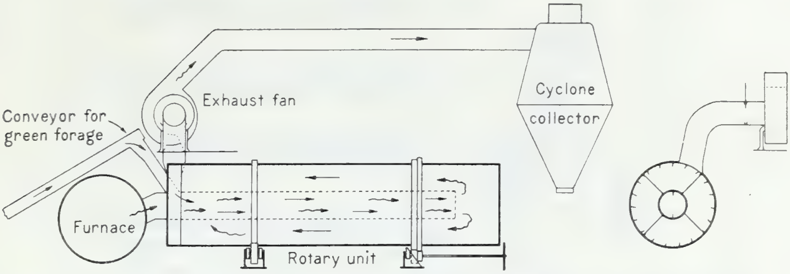

FIGURE 6.—Revolving-drum drier used in forage-drying experiments at Iberia Livestock Experiment Station.

3 feet from the end of the outer cylinder. An exhaust fan was connected to the outer shell at the furnace end in such a manner as to move the furnace gases together with the chopped hay first through the inner cylinder and then back through the outer cylinder. The dried forage, after passing through the fan, was blown into a cyclone. This reverse-current, or two-pass, system lengthened the evaporating zone and greatly increased the efficiency of the machine.

The apron-conveyor and double-drum driers were used in drying about 300 tons of hay, including alfalfa, pasture grass, clovers, and soybean hay. Approximately 250 tons were used in feeding tests with dairy animals, and the rest with beef cattle. In operating these experimental driers, records were kept on the tonnage handled, the power, labor, and fuel requirements, and the moisture content of the forage before and after drying. Similar data were obtained from several Louisiana farms where forage driers were being operated.

Many factors of forage dehydration are difficult to measure precisely. A drying machine handling such a bulky product as forage must of itself be large and attempts to measure air velocities or temperatures or make hydrometric measurements of the drying gases give only approximations. It is impossible to make check runs on the average lot of forage because of the wide range of moisture content within the lot before it enters the drier. The presence of weeds and mixtures of other kinds of forage also affects the data.

The performances of the apron-conveyor and rotary driers located at the Iberia Livestock Experiment Station were observed especially as to the power, labor, and fuel requirements for various kinds of crops, for crops of different maturity, and for different methods of processing. Other factors incidental to these observations were time of the drying run, drier-inlet and exit-gas temperatures, moisture content of forage entering and leaving the drier, the weight of the material entering the drier, and, if possible, the weight of the material leaving the drier. When it was not practicable to obtain the weight of the material on entering and leaving the drier the unknown weight was computed from the known weight and the moisture content of the forage (wet basis) before and after drying. It was assumed that under normal operating conditions the difference between the weight of the forage as it enters and as it leaves the drier represents the water evaporated and that the quantity of dry matter is constant.

From tests of the two driers at the Iberia Station, which have been summarized in tables 1 and 2, the following is noted:

TABLE 1.—*Drying alfalfa, soybean, and cowpea hay with experimental apron-conveyor drier*

WHOLE ALFALFA, FIRST SEASON

Test No.	Duration of test	Temperature of drying air		Weight of forage		Moisture content of forage [1]		Water evaporated	Loss in weight of forage [2]	Power used	Fuel used	Heat input, B. t. u.	Power used [2]		Heat input, B. t. u.[2]		Drier output per hour [2]	Water evaporated per hour [2]
		Inlet	Exit	Entering	Discharge	Entering	Discharge						Per ton of hay	Per 1,000 pounds of water evaporated	Per ton of dried hay	Per 1,000 pounds of water evaporated		
	Hours	° *F.*	° *F.*	*Pounds*	*Pounds*	*Percent*	*Percent*	*Pounds*	*Percent*	*Kilowatt-hours*	*Gallons*	*Millions*	*Kilowatt-hours*	*Kilowatt-hours*	*Millions*	*Millions*	*Pounds*	*Pounds*
1	5.9	------	------	5,745	2,520	63.5	16.7	3,225	56.1	115	105.1	15.40	91.3	35.7	12.22	4.78	427	547
2	5.38	------	------	5,730	2,535	58.1	8.9	3,195	55.8	91	89	13.05	71.8	28.5	10.29	4.08	471	594
3	.41	------	------	795	235	72.7	7.9	560	70.4	11	10	1.47	93.2	19.6	12.46	2.63	573	1,366
4	3.41	------	------	5,795	2,085	71.2	19.9	3,710	64.0	63	65	9.53	60.4	17.0	9.13	2.57	611	1,088
5	4.61	------	------	6,855	2,680	68.2	18.6	4,175	60.9	92	98	14.37	68.7	22.0	10.73	3.44	581	906
6	8.26	320	195	11,495	5,080	61.1	11.9	6,415	55.8	164	156	22.87	64.6	25.6	9.00	3.56	615	777
7	9.58	311	183	13,530	5,685	61.0	7.4	7,845	58.0	203	207	30.35	71.4	25.9	10.68	3.87	593	819
8	2.83	311	170	3,805	1,845	56.4	10.1	1,960	51.5	60	52	7.62	65.0	30.6	8.26	3.89	652	693
9	7.02	353	181	10,310	4,240	60.3	3.4	6,070	58.9	125	151	22.14	59.0	20.6	10.44	3.65	604	865
10	3.17	400	183	4,265	1,645	62.7	3.3	2,620	61.4	57	62	9.09	69.3	21.8	11.03	3.47	519	826
11	2.50	369	178	3,330	1,480	59.0	7.9	1,850	55.6	42	53	7.77	56.8	22.7	10.50	4.20	592	740
12	2.60	------	176	4,295	1,810	60.7	6.7	2,485	57.9	48	56	8.21	53.0	19.3	9.06	3.30	696	956
13	12.75	361	188	18,120	9,160	52.3	5.7	8,960	49.4	238	220	32.25	52.0	26.6	7.04	3.60	718	703
14	7.25	340	136	12,400	7,910	44.2	12.5	4,490	36.2	158	103	15.10	40.0	35.2	3.82	3.36	1,091	619
15	2.16	330	146	3,710	2,325	42.1	7.6	1,385	37.3	45	29	4.25	38.7	32.5	3.65	3.07	1,076	641
16	4.50	------	------	7,185	5,240	31.8	6.5	1,945	27.1	94	62	9.09	35.9	48.3	3.47	4.67	1,164	432
17	1.41	------	------	2,495	1,675	42.7	14.7	820	32.9	26	20	2.93	31.0	31.7	3.50	3.57	1,188	582
18	2.83	248	148	5,665	2,890	52.4	6.6	2,775	49.0	59	52	7.62	40.8	21.3	5.28	2.75	1,021	981
Total or average	86.57	334	171	125,525	61,040	55.8	9.3	64,485	51.4	1,691	1,590.1	233.11	55.4	26.2	7.64	3.61	705	745

SECOND SEASON																		
19	0.42	278	186	442	235	51.0	8.0	207	46.8	9	7.2	1.06	76.6	43.5	9.02	5.12	560	493
20	.33	288	192	398	241	54.0	24.0	157	39.4	6	4.8	.70	49.8	38.2	5.81	4.46	730	476
Total or average	.75	283	189	840	476	52.4	16.1	364	43.3	15	12.0	1.76	63.0	41.2	7.39	4.84	635	485
THIRD SEASON																		
21	22.0	------	------	29,545	15,730	53.2	12.1	13,815	46.8	407	242.0	35.47	51.8	29.5	4.52	2.57	715	628
22	4.75	------	------	4,100	1,565	68.8	18.2	2,535	61.8	86	57.0	8.36	109.8	33.9	10.70	3.30	329	534
23	2.25	------	------	3,795	2,090	53.6	15.7	1,705	45.0	40	33.0	4.84	38.3	23.5	4.62	2.83	929	758
24	11.58	------	------	19,905	8,320	66.9	20.8	11,585	58.2	235	187.0	27.41	56.5	20.3	6.59	2.37	718	1,000
25	13.2	------	------	15,450	6,000	65.6	11.5	9,450	61.2	230	170.0	24.92	76.7	24.3	8.30	2.64	455	716
26	7.55	------	------	11,260	5,040	59.2	8.9	6,220	55.2	107	116.3	17.05	42.5	17.2	6.77	2.74	668	824
27	3.6	------	------	5,350	2,755	55.9	15.1	2,595	48.5	40	60.7	8.90	29.0	15.4	6.46	3.43	765	721
28	3.3	------	------	5,570	3,580	43.1	11.3	1,990	35.7	41	33.0	4.84	22.9	20.6	2.70	2.43	1,085	603
29	3.85	------	------	5,360	2,835	52.7	10.6	2,525	47.1	45	41.5	6.08	31.7	17.8	4.29	2.41	736	656
30	3.82	------	------	7,890	4,380	51.9	13.5	3,510	44.5	98	98.0	14.37	44.8	27.9	6.57	4.10	1,147	919
Total or average	75.90	------	------	108,225	52,295	58.2	13.6	55,930	51.7	1,329	1,038.5	152.24	50.8	23.8	5.82	2.72	689	737
CHOPPED SOYBEAN, FIRST SEASON																		
31	10.41	315–375	240–255	11,800	6,810	54.2	20.7	4,990	42.3	141	203.4	29.82	41.4	28.2	8.76	5.98	654	479
WHOLE COWPEA, FIRST SEASON																		
32	20.8	------	------	21,735	10,055	57.9	9.0	11,680	53.7	257	343	50.3	51.1	22.0	10.0	4.31	483	562

[1] Averages in these columns are weighted.

[2] Averages in these columns are based on total for crop season.

TABLE 2.—*Drying chopped alfalfa, soybean, and cowpea hay with experimental rotary drier*

Test No.	Duration of test	Temperature of drying air		Weight of forage		Moisture content of forage [1]		Water evaporated	Loss in weight of forage [2]	Power used	Fuel used	Heat input, B. t. u.	Power used [2]		Heat input, B. t. u.[2]		Drier output per hour [2]	Water evaporated per hour [2]
		Inlet	Exit	Entering	Discharge	Entering	Discharge						Per ton of hay	Per 1,000 pounds of water evaporated	Per ton of dried hay	Per 1,000 pounds of water evaporated		
ALFALFA (SOME JOHNSON GRASS), THIRD SEASON																		
	Hours	° *F.*	° *F.*	*Pounds*	*Pounds*	*Percent*	*Percent*	*Pounds*	*Percent*	*Kilowatt-hours*	*Gallons*	*Millions*	*Kilowatt-hours*	*Kilowatt-hours*	*Millions*	*Millions*	*Pounds*	*Pounds*
33	8.15	------	------	8,800	2,825	71.3	10.6	5,975	67.9	98	98.0	14.37	69.4	16.4	10.80	2.41	347	733
34	.75	------	------	1,450	392.5	76.1	11.7	1,057.5	72.9	8	14.5	2.13	40.8	7.6	10.87	2.01	523	1,410
35	21.00	------	------	36,100	12,450	69.9	12.7	23,650	65.5	289	351.4	51.52	46.4	12.2	8.28	2.18	593	1,126
Total or average	29.90	------	------	46,350	15,667.5	70.4	12.3	30,682.5	66.2	395	463.9	68.02	50.4	12.9	8.68	2.22	524	1,026
ALFALFA (HEAVY JOHNSON GRASS MIX), FOURTH SEASON																		
36	1.10	------	------	2,525	855	72.7	19.3	1,670	66.1	17	19	2.79	39.7	10.2	6.52	1.67	777	1,518
37	1.00	------	------	1,815	660	68.5	13.6	1,155	63.6	15	20	2.93	45.5	13.0	8.88	2.54	660	1,155
Total or average	2.1	------	------	4,340	1,515	70.9	16.8	2,825	65.1	32	39	5.72	42.2	11.33	7.55	2.02	721	1,345
SOYBEAN, THIRD SEASON																		
38	18.77	------	------	18,745	8,130	64.0	17.0	10,615	56.6	208	172.7	25.32	51.2	19.6	6.23	2.39	433	566
39	2.50	------	------	3,280	1,035	77.2	27.8	2,245	68.4	26	44.0	6.45	50.2	11.6	12.45	2.87	414	898
40	1.60	------	------	2,750	880	67.6	9.3	1,870	68.0	16	46.5	6.82	36.4	8.6	15.50	3.65	550	1,169
41	32.45	------	------	47,535	20,240	63.3	13.8	27,295	57.4	411	515.0	75.50	40.6	15.1	7.46	2.77	624	841
42	6.64	------	------	11,090	5,405	58.0	13.8	5,685	51.3	97	117.0	17.15	35.9	17.1	6.34	3.02	814	856
Total or average	61.96	------	------	83,400	35,690	63.4	14.8	47,710	57.4	758	895.2	131.24	42.5	15.9	7.35	2.75	576	770

SOYBEAN, FOURTH SEASON																		
43 (80-day)	18.35	800	196	28,810	12,730	60.9	11.5	16,080	55.8	310	304.8	44.68	48.7	19.3	7.02	2.78	694	876
44 (80-day)	4.25	765	190	5,970	2,865	62.3	21.4	3,105	52.0	68	70.0	10.26	47.5	21.9	7.16	3.30	674	731
45 (80-day)	3.75	800	220	6,800	3,260	56.9	10.1	3,540	52.1	57	66.8	9.79	35.0	16.1	6.01	2.77	869	944
46 (120-day)	1.20	740	215	2,005	1,025	54.6	11.1	980	48.9	19	20.7	3.03	37.0	19.4	5.91	3.09	854	817
47 (120-day)	1.10	735	195	1,915	730	66.1	11.2	1,185	61.9	16	20.8	3.05	43.8	13.5	8.36	2.57	664	1,077
48 (120-day)	1.15	730	200	2,100	1,170	51.9	13.6	930	44.3	14	14.8	2.17	23.5	15.1	3.65	2.33	1,017	809
Total or average	29.80	787	199	47,600	21,780	60.1	12.7	25,820	54.4	484	497.9	72.98	44.4	18.8	6.70	2.83	731	866
COWPEA, THIRD SEASON																		
49	10.85	------	------	18,220	6,615	68.3	12.7	11,605	63.7	165	212	31.08	49.9	14.2	9.4	2.68	610	1,070
50	1.75	------	------	2,680	1,695	47.5	16.9	985	36.8	16	21	3.08	18.9	16.2	3.63	3.13	969	563
51	4.91	------	------	8,125	3,545	61.2	11.1	4,580	56.4	92	105	15.40	51.9	20.1	8.69	3.36	722	933
52	5.25	------	------	7,800	2,650	74.9	26.2	5,150	66.0	67	87	12.75	50.6	13.0	9.62	2.48	505	981
53	9.03	------	------	14,545	5,190	72.1	21.8	9,355	64.3	117	137	20.10	45.1	12.5	7.75	2.15	575	1,036
Total or average	31.79	------	------	51,370	19,695	68.2	17.0	31,675	61.7	457	562	82.41	46.4	14.4	8.37	2.60	620	996

[1] Averages in these columns are weighted.
[2] Averages in these columns are based on totals for the crop season.

1. In drying alfalfa (whole) on the apron-conveyor drier the average percentage loss in weight was about the same for the first and third seasons. Not much forage was dried during the second season. The power consumed per unit weight of material dried and per unit weight of water evaporated was reduced in the third season from that shown during the first season. The same held true for the heat requirements of the drier per unit weight of material dried and per unit weight of water evaporated, although the hourly output and evaporation weight did not show an increase. This more efficient utilization of power and heat in the apron-conveyor drier was due to blowing the air countercurrent to the apron travel for the first half of the apron length. The intake and exhaust system on the apron-conveyor drier was arranged so that the drying gases after first being forced through a section of the apron might be drawn into a fan and then forced through another section of the apron toward either the feed end or discharge end of the drier. If the air moved toward the feed end, the countercurrent system was obtained; if toward the discharge end (fig. 5), the air moved concurrently with the hay. The air velocity through the mat of forage ranged from 80 to 150 feet per minute in all of these observations.

2. When the apron-conveyor drier was used to dry chopped soybean hay, the drying proved to be very uneven and poor, the average discharge moisture content being approximately 20 percent. At this moisture content it is doubtful whether artificially dried forage will keep in good condition, free from mold and spoilage.

3. Cowpea hay in the apron-conveyor drier presented much the same problem as to nonuniformity of drying as did soybean hay.

4. The data for the fourth season for the rotary drier were taken when the material was further reduced by passing it through a hammer mill after it had been cut in a silage cutter. The power requirements per 1,000 pounds of water evaporated were greater for drying soybean hay in the fourth season than in the third. The heat required per unit of material dried was about the same, but the hourly evaporation was increased from 770 to 866 pounds, an increase of 13 percent. In drying alfalfa there also appears to be an increase in thermal efficiency as well as capacity of the drier due to the shredding of the undried forage with a hammer mill.

5. Data taken on the effect of maturity on power and fuel requirements showed that the 120-day growth Otootan soybean hay required slightly less power and fuel for dehydration than 80-day growth hay of the same variety. This difference was not due to initial moisture content of the green material.

6. The thermal capacity for evaporating moisture was affected materially when the forage was reduced to fine particles. The inner parts of the forage plant came in more direct contact with the drying gases when chopped and shredded than when left whole, as they were in the apron-conveyor drier.

Data were also taken on several commercial driers operating on neighboring plantations. The performances of these driers are summarized in table 3 under the headings of "Single-drum" and "Triple-drum." So far as the data show, the large commercial driers were somewhat more efficient in the utilization of heat than the small experimental units.

TABLE 3.—*Operating data for several early commercial and experimental driers*

Type of drier	Hay	Loss in weight	Output of hay per hour	Water evaporated per hour	Requirement per ton of dry hay obtained				Requirement per 1,000 pounds of water evaporated			
					Fuel		Power	Man labor	Fuel		Power	Man labor
					Oil	B. t. u.			Oil	B. t. u.		
		Percent	*Pounds*	*Pounds*	*Gallons*	*Millions*	*Kilowatt-hours*	*Hours*	*Gallons*	*Millions*	*Kilowatt-hours*	*Hours*
Apron conveyor [1]	Whole alfalfa	51.6	689	736	39.7	5.82	50.8	8.71	18.6	2.73	23.8	4.08
Do [1]	Chopped Biloxi soybean	42.3	654	480	59.7	8.75	41.4	9.17	40.7	5.97	28.2	6.25
Do [1]	Whole native grasses	43.0	901	653	48.1	7.05	35.0	6.66	31.8	4.66	23.2	4.59
Do [1]	Whole cowpea	53.8	483	561	68.2	10.00	51.1	12.4	29.4	4.31	22.0	5.35
Do [1]	Whole lespedeza	56.3	567	701	69.8	10.23	57.4	10.6	27.1	3.97	22.2	4.28
Do [1]	Whole white clover	54.3	709	819	47.1	6.90	58.4	8.23	19.9	2.92	24.6	3.68
Double drum [1]	Chopped alfalfa	58.4	678	902	58.3	8.55	46.2	8.85	20.8	3.05	16.5	3.33
Do [1]	Chopped alfalfa and Johnson grass	65.0	721	1,345	51.4	7.54	42.2	8.32	13.8	2.02	11.3	2.23
Do [1]	Chopped Biloxi soybean	59.1	574	828	56.6	8.30	42.8	10.45	19.6	2.87	14.8	3.62
Do [1]	Chopped Ototan soybean	54.3	730	867	45.7	6.70	44.4	8.22	19.3	2.83	18.8	3.46
Do [1]	Chopped cowpea	57.0	668	916	52.9	7.76	42.9	8.98	20.0	2.93	16.2	3.28
Single drum	Chopped Biloxi soybean	64.4	1,242	2,991	76.1	11.16	27.0	7.3	21.0	3.08	7.45	2.02
Do	Chopped Ototan soybean	69.4	950	2,160	74.5	10.92	34.8	10.6	16.4	2.40	7.7	2.24
Triple drum	Chopped soybean	52.8	2,000	2,185	[2] 4.37	4.37	40.7	8.0	[2] 1.96	1.96	18.5	3.68
Do	Chopped corn and soybean; soybean; velvetbean and corn; hegari; sorghum.	61.7	1,890	3,060	[2] 5.5	5.5	63.5	10.5	[2] 1.71	1.71	19.7	3.26

[1] A small experimental machine.

[2] Thousands of cubic feet of natural gas.

Recent investigations made on a portable dehydrator (fig. 4, p. 4) at the Agricultural Research Center, Beltsville, Md., consisted of determining the performance characteristics of this type of dehydrator and the drying requirements of forage crops. Also the relative efficiency of preservation of the nutrients and the feeding value when fed to dairy cows were compared with other methods of harvesting.

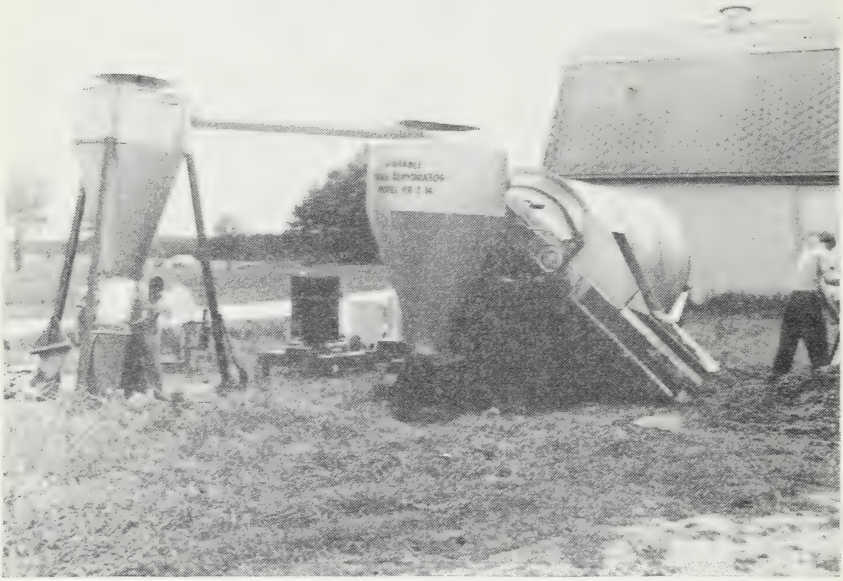

FIGURE 7.—Portable forage dehydrator tested at the Agricultural Research Center, Beltsville, Md.

Figure 7 shows the machine during test. The machine is mounted on wheels. When it is to be transported, the collector standing on the ground and the feed conveyor are disconnected and moved separately. The machine consists of a 3-foot combustion chamber which extends part way inside the 5-foot cylinder. The 5-foot cylinder or drum is closed at the back end except where the high-moisture forage enters. The outer drum is 7 feet in diameter and 14 feet long. It has an opening near one end from which the forage is lifted by suction and passed on to the coolers. Flanges or flights are attached to the inside of the drum for lifting and spreading the chopped forage through the drying chamber as the drum revolves. Heat is supplied by an oil burner located at the opposite end of the drum from where the forage enters. Controls regulate the rate of fuel burning to maintain a uniform outlet air temperature. A 20-horsepower gasoline engine is used for supplying power to the machine.

The time required for the forage to pass through the dehydrator is relatively short, only a few minutes. As the forage loses moisture its movement through the drier is speeded up. For this reason, overdrying and scorching are minimized. For good results the forage should be chopped to a fine uniform cut, preferably ¼-inch machine cut.

The summary of tests made on the portable dehydrator is shown in table 4, page 16. The capacity of the dehydrator when drying high-moisture forage was approximately 500 pounds of dried forage per hour for the first season. This required the burning of approximately 16 gallons of No. 2 fuel oil. Replacement of burner equipment with that of larger capacity and slight modifications of air inlet openings increased the capacity of the machine during the second season. The fuel-burning rate was increased to approximately 20 gallons of No. 2 fuel oil per hour. The higher burner capacity raised the average inlet temperature of the drum and consequently required very close regulation of the machine adjustment; otherwise scorching of the forage resulted. The automatic controls permitted the temperature inside the drum to fluctuate to an extent that the moisture content of the forage leaving the drum was not uniform. Variations of a few percent in moisture in the loads of chopped forage brought to the dehydrator required changes of the forage feed rate and outlet temperature adjustments. This required considerable manual attention.

A minimum of three men was required to harvest and dehydrate forage when using this machine. One man was needed to operate the field chopper and haul the forage to the dehydrator, another to feed the chopped forage into the feed conveyor, and the third to sack the dehydrated meal and to operate the dehydrator controls. For long hauling distances, it may be necessary to have a fourth man, so green forage can be kept at the dehydrator at all times.

Air temperatures at the point where green forage entered the drying-drum were as low as 800° F. and as high as 1,300°, depending upon the drying requirements. The drum outlet temperatures were regulated from 225° when drying forage of low moisture content to 300° for forage of high moisture content. Greater moisture contents of the forage required higher outlet temperatures. The forage from the dehydrator for the above tests ranged from 6 to 12 percent (wet basis).

The dried forage when sacked from the last cooling collector ranged in temperature from 113° to 142° F.

Forage stored at these high temperatures lost carotene very rapidly until cooled to near atmospheric temperature. Storing sacked dried forage in narrow piles with free circulation of air around two sides of the sacks promoted cooling and resulted in lower carotene loss. Forage stored loose in bins held heat longer than that stored in sacks and lost more carotene.

USE OF DRIERS

Capacity

Alfalfa when cut for hay may contain more than 70 percent moisture. When such material is hauled to the drier and dried immediately, as much as 4,133 pounds of water must be evaporated to produce 2,000 pounds of hay containing 8 percent moisture (fig. 8). If the hay is left in the swath for several hours its moisture content may be

TABLE 4.—*Operating data for drying alfalfa and for drying oats-*

FIRST SEASON

Crop	Duration of test	Temperature of drying air		Weight of forage		Moisture content of forage		Water evaporated	Loss in weight of forage
		Inlet	Exit	Entering	Discharge	Entering	Discharge		
	Hours	°*F.*	°*F.*	*Pounds*	*Pounds*	*Percent*	*Percent*	*Pounds*	*Percent*
Oats-brome-alfalfa mixture	6.16		270–290	10, 816	3, 850	66. 9	13. 0	6, 739	64. 4
First cutting alfalfa	5. 80		255–270	11, 119	2, 779	74. 6	12. 4	7, 949	75. 0
Second cutting alfalfa	8. 38		270–290	14, 662	4, 141	73. 8	9. 1	10, 448	71. 8
Third cutting alfalfa:									
Test No. 1	2. 04	650–880	240–265	3, 591	1, 415	63. 6	8. 3	2, 167	60. 6
Test No. 2	1. 40	400–600	210–245	2, 515	1, 243	49. 9	7. 2	1, 167	50. 6
SECOND SEASON									
Second cutting alfalfa	15. 36	700–1300	240–295	38, 179	13, 440	64. 5	6. 4	23, 766	64. 8
Third cutting alfalfa	5. 45	850–1300	250–295	14, 009	4, 238	66. 9	5. 7	9, 134	69. 7

reduced to about 55 percent. Under such conditions it will be necessary for the machine to evaporate 2,089 pounds of water to produce a ton of hay at 8 percent moisture. In the latter case the capacity of the drier in tons of hay per hour may be twice as great as with 70-percent moisture-content forage.

The capacity of a drier will depend also somewhat upon the kind of forage, the degree of processing before it is fed to the machine, and the condition of the air entering the drier. When drum driers are used, the fineness and uniformity of chopping greatly influence the performance of the machine. Alfalfa, some varieties of clover, and meadow grasses usually dry much more easily than soybean hay or other coarse-stem plants. The capacity of a drier is frequently referred to in terms of tons of dried material delivered per hour. Although this method gives an indication as to what tonnage may be expected under some conditions, it may be misleading unless reference is also made to the initial moisture content and kind of forage dried.

Forage driers may be obtained with rated capacities ranging from approximately 1,000 to 12,000 pounds of water per hour.

FURNACE AND FUELS

A properly designed furnace of ample size is important for a forage drier, as air much in excess of that required for complete combustion is drawn through the furnace. The capacity of the furnace should be large enough and the size of the openings great enough so as to not unduly increase resistance to the flow of the drying gases. With a drum drier the air requirements at the discharge fan are taken roughly as the equivalent of 1.2 cubic feet of dry air per minute per pound of water evaporated per hour. Since the temperature of the drying gases at the discharge end is about 250° F. and that at the drier inlet is about *brome-alfalfa mixture with drum-type portable dehydrator*

FIRST SEASON—Continued

Power used (gasoline)	Fuel used (No. 2 fuel oil)	Heat input, B. t. u.	Power used		Heat input B. t. u.		Drier output per hour	Water evaporated per hour	Temperature of dehydrated forage in sack
			Per ton of hay (gasoline)	Per 1,000 pounds of water evaporated (gasoline)	Per ton of dried hay	Per 1,000 pounds of water evaporated			
Gallons	*Gallons*	*Millions*	*Gallons*	*Gallons*	*Millions*	*Millions*	*Pounds*	*Pounds*	°*F.*
8.4	96.5	13.51	4.38	1.25	7.01	2.00	625	1,094	120–138
7.0	99.3	13.91	5.01	.88	10.01	1.75	479	1,371	117–123
11.7	135.8	19.01	5.67	1.12	9.18	1.82	494	1,247	113–126
2.6	24.2	3.38	3.69	1.21	4.78	1.56	694	1,062	124–140
1.8	14.8	2.07	2.86	1.54	3.30	1.77	888	833	124–142

SECOND SEASON—Continued

Power used (gasoline)	Fuel used (No. 2 fuel oil)	Heat input, B. t. u.	Power used per ton of hay (gasoline)	Power used per 1,000 pounds of water evaporated (gasoline)	Heat input per ton of dried hay	Heat input per 1,000 pounds of water evaporated	Drier output per hour	Water evaporated per hour	Temperature of dehydrated forage in sack
25.3	298.8	41.82	3.76	1.06	6.22	1.76	875	1,547	120–140
11.3	108.1	15.13	5.32	1.24	7.14	1.66	778	1,676	118–148

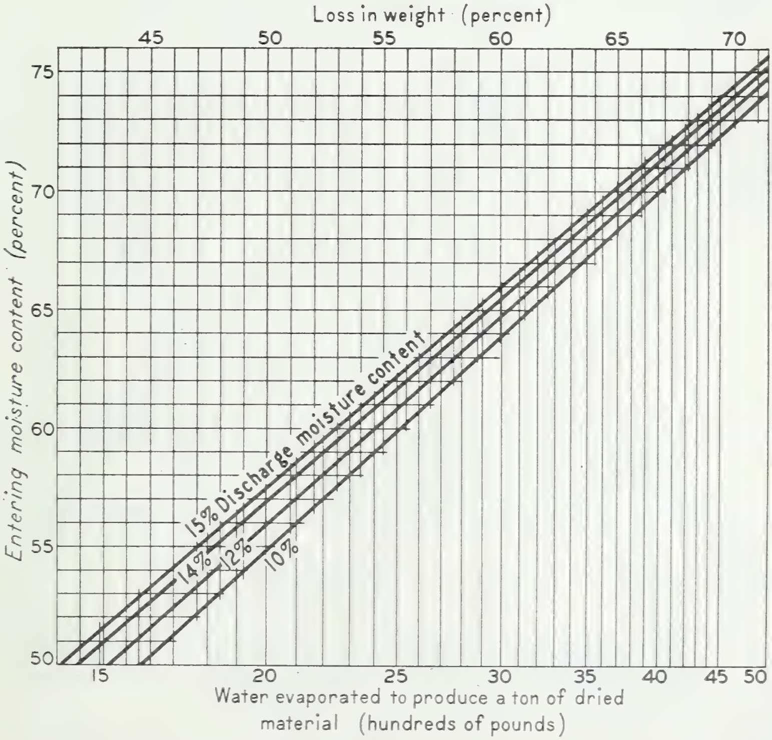

FIGURE 8.—Quantities of water evaporated and loss in weight in drying hay from and to different moisture contents.

1,500°, the inlet volume is about three times greater than the volume at discharge. Therefore, a drier with an evaporative capacity of about 3,000 pounds of water per hour should allow the passage of about 10,800 cubic feet of air per minute at the inlet. The entrance velocity should not greatly exceed 1,500 feet per minute. For a drier with a thermal efficiency of 60 percent the evaporation of 3,000 pounds of water will require about 5,500,000 British thermal units (B. t. u.). This quantity of heat would be supplied by 40 to 45 gallons of fuel oil or 5,500 cubic feet of natural gas.

In practice, final dilution of furnace gases takes place at the secondary air inlet. This inlet is so arranged that the atmospheric air is

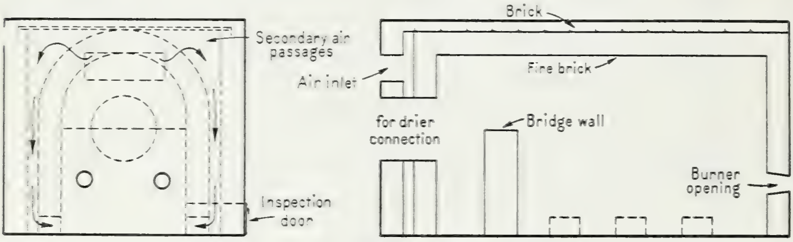

FIGURE 9.—Dutch-oven furnace.

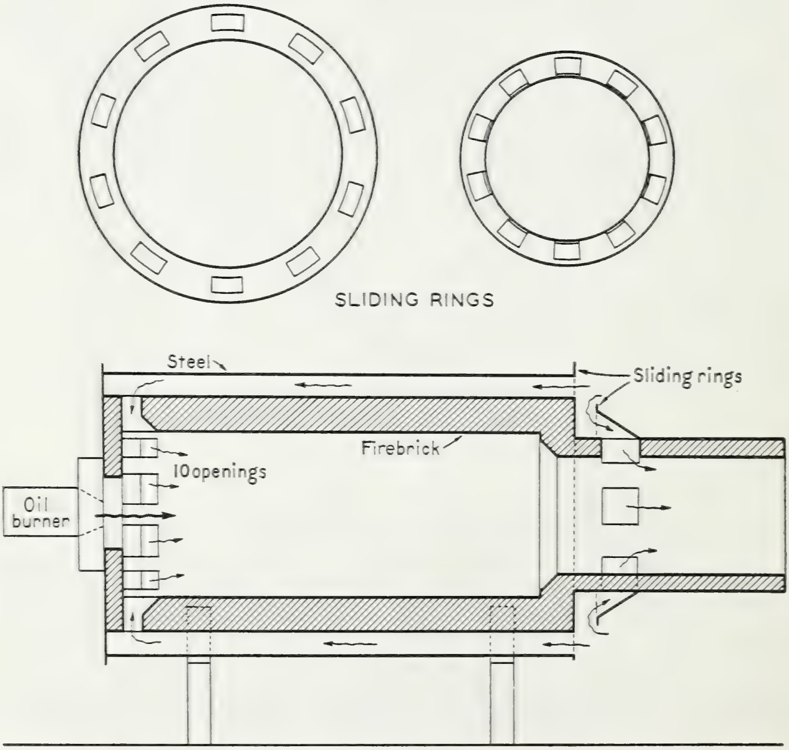

FIGURE 10.—Cylindrical furnace, with sliding rings for controlling air flow.

warmed by passing over heated portions of the exterior of the combustion chamber (note drawing of Dutch-oven type of furnace, fig. 9). The furnace gases may be still further diluted by providing an opening just ahead of the drier inlet, although this is not essential.

Furnace design may be of either the cylindrical or rectangular cross section (figs. 9 and 10). The rectangular-cross-section furnace is usually termed the Dutch-oven type. These two general types of furnaces are adaptable for burning either oil or gas fuels.

The problem of utilizing solid fuels in drying forage is one requiring special consideration so that the drying gases are rendered smokeless and do not contain incandescent particles of flying ash. Oil- or gas-burning equipment possesses advantages that place the coal- or coke-burning furnace at a disadvantage for hay driers unless a mechanical stoker is available.

In order not to localize the combustion of the fuel in too small a space it has been found that, with the fuel oil used at Jeanerette, from 1.75 to 2 pounds of oil may be fired per hour per cubic foot of combustion space. This quantity of oil has a heat value of about 33,000 B. t. u.

In drying hay the combustion of fuel capable of generating approximately 5,500,000 B. t. u. of heat energy was required to evaporate 3,000 pounds of water per hour. On this basis a combustion chamber with a volume of from 165 to 175 cubic feet is needed. For practical purposes the dimensions might be as follows: Width 4 feet, height to top of arch 5 feet, and length to bridge wall 10 feet.

The combustion of gaseous fuels is relatively simple, requiring only a suitable mixing carburetor. For oil fuels it is essential that there be smokeless combustion, which can be accomplished only by thorough atomization of fuel. Under ordinary conditions, satisfactory results are more certain if oil having a specific gravity less than 0.93 is used. This specific gravity corresponds to 20.6° A. P. I. (American Petroleum Institute). Fuels heavier than this usually require preheating equipment in order to insure proper combustion.

POWER REQUIREMENTS

In forage drying, power is needed for the following purposes:

1. Processing the undried forage. This includes chopping, chopping and shredding, or crushing, depending upon the type of drier and the operator's preference.
2. Conveying the drying gases to the drier from the furnace, and removing them after they have performed their work in vaporizing the moisture from the forage.
3. Transporting the dried forage to a storage structure or processing plant either by a drag conveyor or a pneumatic system or a combination of both.
4. Miscellaneous uses such as operating fuel pump and blower for the burner, rotating the drum or actuating the apron conveyor of the drier, operating the unloading hoist, baling or grinding the dried material, etc.

The choice of the power unit depends somewhat on its availability and the cost per unit of energy. From the standpoint of convenience, electric power has the advantage. Where electric energy is available, in most instances the rates are low enough for its profitable use.

Examination of table 3 shows that the power requirements for the experimental apron-conveyor drier ranged from 22 to 28.2 kilowatt-hours per 1,000 pounds of water evaporated. The power requirements are distributed approximately as follows:

	Percent
Moving apron and auxiliary conveyors	11
Moving drying gases	83
Oil-burner operation	6

For an experimental rotary drier the power requirements ranged from 11 to 19 kilowatt-hours per 1,000 pounds, distributed roughly as follows:

	Percent
Chopping forage	25 to 35
Moving drying gases	45 to 60
Oil-burner operation	4 to 8
Rotating drum and conveying forage	10 to 15

With these figures in mind it will be found that a drum drier capable of evaporating 3,000 pounds of water per hour will need motive power equivalent to 35 or 40 horsepower to run it. This would be divided as follows:

	Horsepower
Chopper	15
Fan and drum	20
Burner	1½
Conveying equipment	3

Induction-type electric motors are widely used on drier equipment. They should be enclosed to protect the windings from the fine dust usually found in the air around the drying plant.

OPERATION OF DRIERS

Careful planning of a drying installation will effect economies in all of the important items affecting the efficiency and cost of operation. The operation of a typical drum-drying plant may be described as follows: Forage is cut, chopped, and blown into trucks or trailers with a field chopper. It is then transported to and dumped into the automatic feeder of the dehydrator. The feeder conveys the chopped alfalfa to the drying-drum—from the drum the dried forage is conveyed through one or more cooling cyclones to a hammer mill—then through one or more cyclones for further cooling and finally to a sacker. The dried forage is conveyed by means of a system of pipes and fans or conveyors to the cooling cyclones, hammer mill, and sacker. When meal is pelleted, it is treated with steam or water spray as required for a binding agent, then is run through a pellet machine. Since the temperature of dried meal is raised in the pelleting process, the meal is run through a cooling chamber. The pellets enter the top of the cooling chamber and are drawn off the bottom in a continuous stream. Any fine meal found with the pellets is usually screened out and passed through the pellet machine.

Meal is sometimes blended to obtain a desired protein and carotene analysis. If this is done at time of dehydration and before sacking operations, considerable savings in labor and cost can be made.

Crushers are sometimes used to reduce the chopped green forage to a small uniform size to promote faster and more uniform drying. This equipment is placed between the automatic feeder and drying chamber.

The following points should be kept in mind regarding drier operation:

1. For a drum drier the forage should be reduced to a uniform size, the size of the particles not being greater than about three-eighths of an inch in any one dimension.

2. The inlet temperature should be kept as high as possible, preferably around 1,400° to 1,500° F. Temperatures in excess of these can be used, but corrosion of the brick and steel work may occur more readily at temperatures in excess of 1,500°.

3. The temperature of the exhaust gases should range between 225° and 325° F. for a drum drier, depending upon the initial moisture content of the forage.

4. The furnace, drum, fans, and cyclones should be close-coupled to eliminate piping resistance.

5. Penumatic conveyors for chopped forage require slightly more power than do drag conveyors. Pneumatic conveying of the dried product allows greater flexibility than do drag methods. However, from the standpoint of fire prevention, any smoldering sparks of forage will be more readily detected in the open conveyor than in other systems of conveying. In any case the stored product should be watched for several days. For horizontal runs of pneumatic systems the air velocity should be about 4,000 feet per minute.

6. The matter of fire prevention is important at the forage-drying plant. Unforeseen stoppages and breakdowns may result in fire outbreak. Convenient garden-hose connections with short pieces of hose will pay for themselves many times over in extinguishing fires as they begin. If water under pressure is not available, water barrels with hand-pump tanks should be on hand. In addition, installation of a 20-pound dry-powder type hand fire extinguisher is recommended for use on electrical or oil fires. Forage driers should not be placed in barns or buildings where quantities of inflammable farm products are stored. An inexpensive fire-resistant shelter for the drying plant can be made from second-hand steel pipe and corrugated sheet-metal roofing.

7. It is very important that the forage be thoroughly dried down to its safekeeping moisture content, which for practical purposes should approximate 8 to 9 percent. Too often the inexperienced operator attempts to increase the output of the drier beyond its capacity without due regard to the heat input. The result is a partially dried product that may mold or may heat sufficiently to cause spontaneous combustion. Whole field-cured hay usually can be stored with a moisture content of from 15 to 25 percent, depending upon locality, without danger of heating. Experience indicates that artificially dried hay, especially when chopped, should have a lower moisture content. Such material, when conveyed directly to a bin from the drier, has a higher temperature than that of the atmosphere and there is likely to be some variation in the moisture content of the particles.

PRESENT STATUS OF DEHYDRATION INDUSTRY

A 1949 survey in several of the major dehydration sections in the Middle Western States revealed that practically all of the dehydrators now in use are of the drum type and have a rated capacity to evaporate 6,000 pounds of water per hour. A few have capacities to evaporate 12,000 pounds of water per hour.

The drums vary in size and are either single- or multiple-pass. Single-pass drums vary from 8 to 10 feet in diameter and from 28 to 40 feet in length. The multiple-pass drums are 8 feet in diameter and 24 feet long. The majority of the drums are of manufacturer's design. A few of the manufactured drums are modified to suit the owner. Other drums are entirely of the owner's design and are of the single-pass type.

Equipment of a plant is arranged to meet the desire of the owner, or some particular local problem. However, convenient and accessible space is provided at the plant for trucks or trailers transporting the wet forage to the feeder of the dehydrator. Warehouses and sacking rooms are usually located next to the railroad siding to facilitate loading dehydrated meal into box cars. Plant installations consist of one-, two- or three-drum drying units. Tube-type furnaces with gas burners (fig. 3) are being used on the majority of the drum driers and are of more simple design than that shown in figure 10.

Self feeders, field choppers, and mechanical unloading equipment have eliminated much of the manual labor (fig. 11).

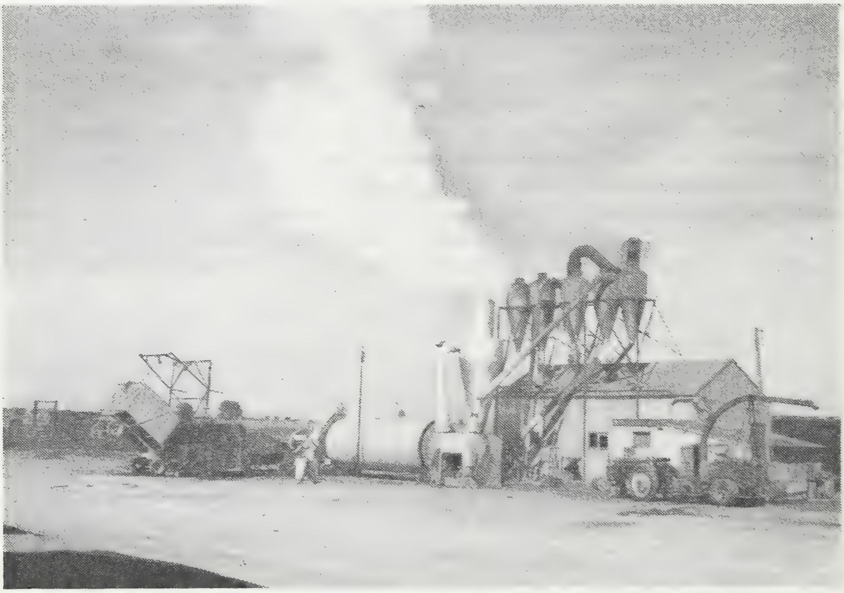

FIGURE 11.—Typical one-drum dehydration plant in operation at Hawley, Colo.

A dehydration plant should have as a minimum the following equipment:

1 drying drum with furnace, burners, and power unit.
1 self-feeder with conveyor to drum and power unit.
2 cyclones.
1 hammer mill and power unit.
1 sacking spout.
Conveyors, piping, blowers, and motors to carry dried forage to the cyclones and sacker spout.
1 scale (for weighing 100-pound sacks of meal).
3 trucks or 2 trucks and 4 trailers.
1 self-propelled field harvester or 1 tractor and field harvester with cutter attachment.
Unloading hoist or truck equipped with hydraulic lifts.
Shop repair tools and equipment (welders, drill press, etc.).
Sacking and storage building.

To keep the plant in continuous operation, it is also advisable to have spare parts, such as sickle parts, grinder hammers and screens, and duplicate equipment for replacements of equipment subject to excessive wear or frequent breakdowns.

Other equipment often used as part of a dehydration plant includes the following items: Dust collectors (in addition to cooling collectors) to reduce dust around the plant and to retain a larger percentage of the alfalfa, pellet equipment, cooling equipment, sifters, packers, crushers, and self-unloading trailers.

The power requirements vary considerably, depending upon the amount of equipment used. The connected electrical load for each drying-drum unit ranges from 130 to 350 horsepower, depending upon the amount and size of equipment used. Grinders require the most power and are usually powered with either 125- or 150-horsepower motors.

The arrangement of the plant equipment will determine to a large extent the amount of space needed for convenient operation. The average size plot of land used for the dehydration plants that were surveyed was 2¼ acres.

Some building and storage space is desirable and usually provided at the dehydration plant to house grinding, sacking, pelleting, and mixing equipment. However, many of the dehydration plants install the drying drums and self feeders outdoors (figs. 12 and 13).

Field harvesters that cut the standing crop or gather the forage from windrows and convey it into wagons or trucks have replaced, almost entirely, the use of loaders for loading long hay and stationary choppers at the drying drums. Trucks with or without trailers are used almost entirely for hauling chopped forage from the field to the drier. Only when distances are short are tractors sometimes used to pull trailers.

Where there are plentiful supplies available, natural gas is used almost entirely for fuel. It burns easily with no smoke and requires little attention once the equipment is properly installed.

The acreage needed to provide alfalfa for continuous operation of each drum of a dehydration plant depends on the yield. The average for all one-drum plants was 550, 600, 800, and 950 acres, respectively, for the first, second, third, and fourth cuttings. The farthest hauling distance of green forage averaged 11 miles for all the plants surveyed.

The investment cost of the surveyed plants varied considerably,

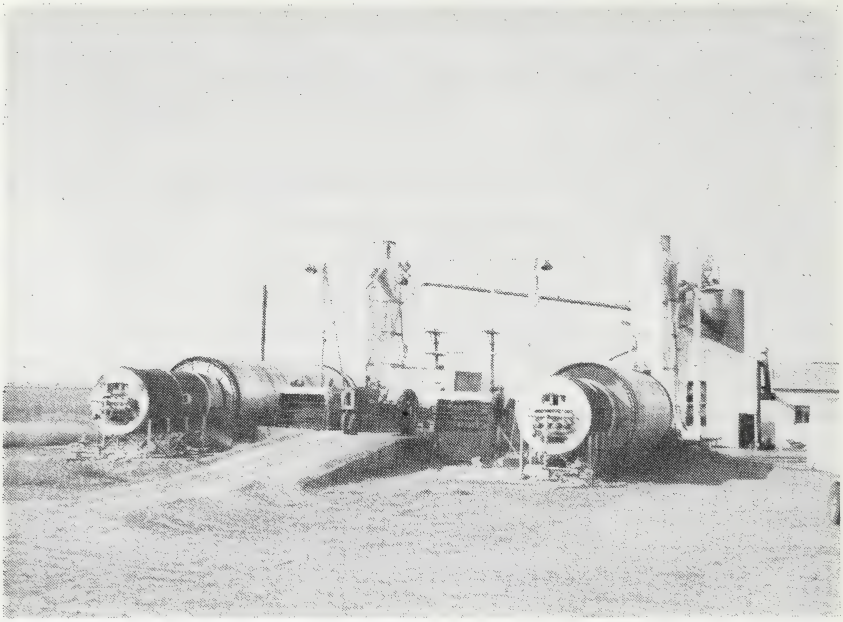

FIGURE 12.—Two-drum plant at Hastings, Nebr., with central unloading platform serving self-feeders for both drying drums.

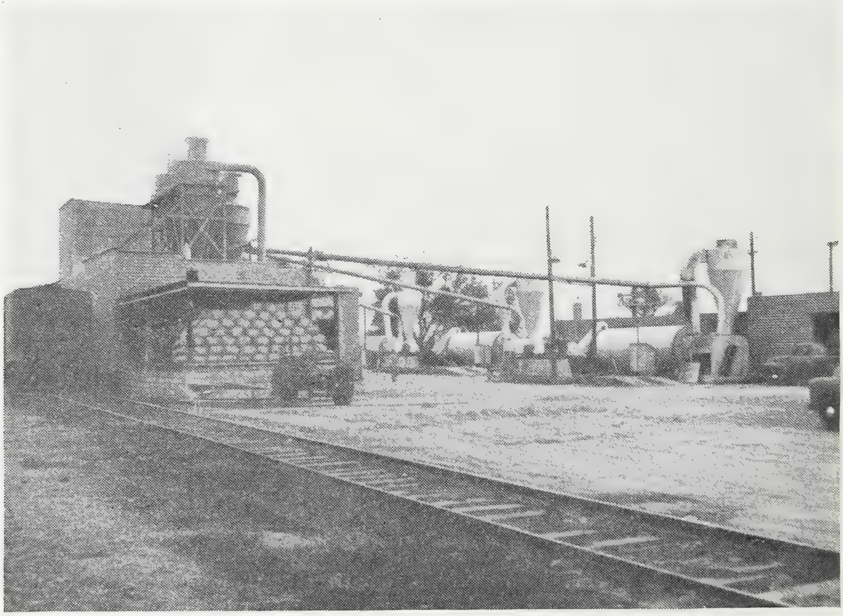

FIGURE 13.—Three-drum installation on a railroad siding near Lexington, Nebr.

ranging from $40,000 to $190,000 for each drying drum installed. One-drum unit plants averaged $95,000, while two-drum unit plants averaged $150,000. This included the cost of field machines, trucks, trailers, plant equipment, buildings, and installation costs. The plants ranged in age from 1 to 10 years.

The production of meal per plant averaged 2,470 tons per drying drum during the growing season of the survey. Under normal operating conditions, this will amount to 1 ton of meal per hour for a machine with capacity to evaporate 6,000 pounds of water per hour. The majority of the plants attempt to operate 24 hours per day during the growing season, when forage is available. The average size crew exclusive of office help or manager averaged 7, 11, and 15 men, respectively, for 1-, 2-, and 3-drum plants. A typical 7-man crew may consist of 1 plant operator and feeder, 2 sackers and storage operators, 1 field operator, 2 haulers, and 1 repairman.

The cost of operating a drier (power, labor, and fuel) depends upon the thermal efficiency of the drier; the initial moisture content of the forage; the unit costs of power, labor, and fuel; the atmospheric conditions; the kind of forage to be dried; and other variables. The total cost of producing a ton of dehydrated alfalfa in 1949 averaged $37 for those plants surveyed. The cost of the various operations and items to produce a ton of dehydrated alfalfa varied considerably from one plant to another. Several of the processing costs averaged as follows: Direct labor for processing, $8.30; natural gas, $2.20; electricity, $1.60; repair parts, $2.60; bags, $4; amount paid to growers, $10. Other items such as blending, pelleting, storage, management, office personnel, taxes, interest, depreciation of equipment and investment make up the remainder of the expenses.

FEEDING VALUE OF DEHYDRATED FORAGE

A considerable tonnage of dehydrated forage, principally dehydrated leaf meal, is produced in this country each year. The production of dehydrated leaf meal amounted to 724,300 tons in 1948–49.

Most of the dehydrated leaf meal is used in poultry feeds, as 3 to 10 percent of the mixture, but some of it is also used in calf starters and swine rations. The leaf meal is used in these feeds and rations primarily as a source of carotene (provitamin A) and riboflavin (vitamin B_2), but it also contains other properties of known nutritive value and possibly some that are unknown.

Considerable interest has developed during the last 15 years in the possibility of dehydrating forage to feed milking cows, because of (1) the possibility of preventing losses of dry matter that occur during field curing, which in the case of alfalfa may amount to 25 percent even under excellent curing conditions; (2) the possibility of producing a feed, by cutting and dehydrating the forage at an early stage of maturity, that can be used in place of all or part of the grain ration; and (3) the possibility of conserving the original vitamin and mineral content of the forage, which would make it equal to excellent summer pasture.

Studies by the Vermont Agricultural Experiment Station show the relative losses of dry matter and nutrients from legumes such as alfalfa and clover and from a grass crop such as timothy, during harvesting and storage, when the crop was preserved as field-cured hay or as artificially dried hay (table 5).

TABLE 5.—*Dry matter and nutrient losses from grassland forage during making and storage as field-cured and artificially dried hays*[1]

Crop and method of drying	Dry matter	Protein	Fiber	Ether extract	N-free extract	Ash
SUN CURING	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Alfalfa (first cut)	23.6	29.4	7.1	41.0	30.8	20.5
Alfalfa (second cut)	13.4	20.7	3.9	37.7	10.7	25.2
Clover	36.1	39.8	29.5	52.6	37.7	39.2
Timothy (early cut)	8.6	11.2	2.0	14.4	10.0	22.1
Average	20.4	24.3	10.6	36.4	22.3	26.7
ARTIFICIAL DRYING						
Alfalfa (first cut)	3.2	14.4	[2] +7.4	[2] +4.1	4.4	12.4
Alfalfa (second cut)	6.8	13.4	8.2	[2] +10.1	.1	17.8
Clover	2.8	14.7	[2] +.6	2.6	.4	5.6
Timothy (early cut)	6.9	4.1	9.2	[2] +12.0	7.0	6.3
Average	4.9	11.7	2.4	[2] +5.9	3.0	10.4

[1] Adapted from Camburn, O. M., Ellenberger, N. B., Jones, C. H., and Crooks, G. C. 1942. The conservation of alfalfa, red clover, and timothy nutrients as silages and as hays. II. Vt. Agr. Expt. Sta. Bul. 494, 40 pp.

[2] Gain, not loss.

On the average, the loss of dry matter incident to field curing these crops was about 20 percent, whereas the loss incident to dehydration was only about 5 percent. It is interesting to note also that, as would be expected, dehydration resulted in greater savings of dry matter from the legume crops than from the grass crop. From these figures it seems probable that on the average 15 to 20 percent more dry matter could be saved if legume crops were preserved by dehydration instead of by field curing.

In experiments conducted at Beltsville the loss of carotene from chopped alfalfa, dehydrated in a commercial portable drier, varied from 2.2 to 28 percent. In one instance where there was considerable browning of the dehydrated hay because of excessive heat, the loss amounted to 44 percent. It would thus appear that excessive temperatures can cause a considerable loss of carotene during dehydration, but where the temperature is carefully controlled, the loss of carotene is small.

TABLE 6.—*Comparative nutritional value of grassland forage made by field curing and artificial drying*[1]

Kind of forage	Digestible protein		Total digestible nutrients	
	Field-cured hay	Artificially dried hay	Field-cured hay	Artificially dried hay
	Percent	*Percent*	*Percent*	*Percent*
Alfalfa (first cut)	10.9	10.3	56.4	60.0
Alfalfa (second cut)	14.7	13.8	57.1	60.2
Clover	8.2	8.0	63.3	61.8
Timothy (early cut)	4.8	4.6	66.4	65.8
Average	9.6	9.2	60.8	61.9

[1] Adapted from Camburn, O. M., Ellenberger, N. B., Jones, C. H., and Crooks, G. C. 1942. The conservation of alfalfa, red clover, and timothy nutrients as silages and as hays. II. Vt. Agr. Expt. Sta. Bul. 494, 40 pp.

The digestibility of the nutrients in forage is not impaired by dehydration, provided the forage is not exposed to excessive drying temperatures (table 6). It should be pointed out, however, that the digestibility of the protein may be lowered if the exhaust temperature of the dehydrator exceeds 350° F., in which case the feeding value of the forage would be affected materially.

Several experiment stations have considered the possibility of substituting dehydrated forage, made from crops cut at an early stage of maturity, for all or part of the grain or for part of the forage in the usual dairy ration. That such substitution might be feasible is indicated by the composition of early-cut forages as compared with some of the feeds commonly fed to dairy cows (table 7). These figures show that, on the basis of total digestible nutrients, dehydrated young grass is intermediate in value between the regular hays and grains fed to dairy cattle.

In feeding trials at the Vermont Agricultural Experiment Station, in which dehydrated young grass was substituted for all the concentrates and the cows continued to receive full amounts of hay and silage, milk and butterfat yields were lowered, apparently because of the excessive bulk of the ration. In other trials at the same station, in which dehydrated young grass was substituted for some of the grain and for one-third of the usual amount of hay and silage, cows produced as much milk, and they produced it almost as efficiently, as when they were fed full allowances of grain, hay, and silage. The young grass contained 20.4 percent of crude protein, 17.6 percent of crude fiber, 40.2 percent of nitrogen-free extract, 3.4 percent of ether extract, and 63.6 percent of total digestible nutrients, whereas the corresponding percentages in the grain ration were 20.4, 6.3, 51.9, 4.5, and 72.9.

In feeding experiments conducted by the Bureau of Dairy Industry in cooperation with the Washington Agricultural Experiment Station, it was concluded that artificially dried pasture herbage containing 20.7 percent of protein and 15.8 percent of crude fiber could be used efficiently in replacing at least a part of the concentrate mixture for milking cows.

In another experiment by the Bureau of Dairy Industry, four cows that were fed dried immature pasture grass as the sole ration averaged 11,325 pounds of milk, which was 64.6 percent of their average pro-

TABLE 7.—*Comparative composition of grains, hays, and dehydrated young grass*

Feed	Dry matter	Crude protein	Crude fiber	Nitrogen-free extract	Ether extract	Total digestible nutrients
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Grain mixture [1]	88.6	20.6	6.7	51.4	4.5	72.6
Corn No. 2 [2]	85.0	8.6	2.0	69.3	3.9	80.1
Barley	89.4	12.7	5.4	66.6	1.9	77.7
Dehydrated young grass [1]	89.6	20.7	17.4	40.7	3.3	64.1
Dehydrated young Sudan grass [2]	86.4	14.2	18.8	42.4	2.4	58.9
Dehydrated pasture herbage [3]	86.1	24.6	18.1	39.2	3.5	64.7
Dehydrated alfalfa leaf meal	93.6	18.9	24.3	38.1	2.8	54.7
Alfalfa [4]	90.5	14.8	28.9	36.6	2.0	50.3
Timothy hay [1]	86.3	7.3	30.1	42.4	1.5	46.6

[1] Camburn, O. M. 1934. The feeding value of artificially dried young grass, III. Vt. Agr. Expt. Sta. Bul. 368, 10 pp.

[2] Newlander, J. A. 1935. The digestibility of artificially dried Sudan grass. Vt. Agr. Expt. Sta. Bul. 386, 8 pp., illus.

[3] Hodgson, R. E., and Knott, J. C. 1932. Apparent digestibility of, and nitrogen, calcium, and phosphorus balance of dairy heifers on, artificially dried pasture herbage. Jour. Agr. Res. 45 (9): 557-563.

[4] Morrison, Frank B. 1948. Feeds and feeding, a handbook for the student and stockman. Ed. 21, unabridged, 1207 pp., illus. Ithaca, N. Y.

duction (17,517 pounds) under full feed conditions with grain. The dried grass contained 14.8 percent of protein and 28.1 percent of crude fiber.

It seems reasonable to conclude that dehydrated immature forage can be substituted for as much as one-third to one-fourth of the roughage part of the ration and two-thirds of the grain ration for cows producing at the rate of 30 pounds or more of 4-percent fat-corrected milk daily. At lower rates of production, the dehydrated immature forage could be substituted for all the grain in the ration.

Whether such a practice would be feasible is largely a matter of economics. If the dried forage can be purchased or produced at a cost midway between the cost of a good grade of alfalfa hay and the cost of a grain ration of 18-percent protein content, it can be used on the same basis as these feeds.

In an experiment conducted at the Agricultural Research Center in 1948, alfalfa was harvested at the usual hay stage and preserved by three different methods: (1) Wilted silage, (2) barn-dried hay, dried with heated air, and (3) dehydrated hay. Less protein, carotene, and dry matter was lost by the dehydration method than by the other methods. In feeding trials the dehydrated hay proved to be slightly more palatable than the wilted silage or barn-dried hay, but milking cows produced equally well on all three kinds of forage.

In experiments at the Pennsylvania Agricultural Experiment Station, sun-cured hay and dehydrated hay from the same field were fed on an equal dry-matter basis to dairy heifers to study the rate of gain in body weight. The results are shown in table 8. In these experiments the dehydrated hay proved to be more palatable than the sun-cured hay, and it produced better gains.

Interest is now developing in the possible use of pelleted dehydrated forage for dairy cattle. The pellets vary from one-fourth to one inch in diameter. Forages in this form can be shipped at lower freight costs than baled hay. It is possible that the pelleted forage can be used as feed for dairy cattle in much the same way as dehydrated young forage, that is, as a substitute for some of the grain and roughage in the dairy ration. Pelleting gets away from the dustiness of ground or finely chopped forage. In preliminary experiments by the Bureau of Dairy Industry, growing heifers have consumed about as much dry matter from the pelleted form of forage as from field-cured hay.

TABLE 8.—*Effect of method of curing hay on gain in weight of dairy heifers*

Kind of hay	Days on experiment	Number of animals on experiment	Average daily gain	
			Dehydrated hay	Sun-cured hay
			Pounds	*Pounds*
Oat hay	86	26	1.46	1.17
Oat and pea hay	138	[1]8	1.44	1.34
Do	138	[2]8	1.17	1.02
Mixed timothy and clover	56	[1]18	1.30	1.11
Do	136	[2]8	1.22	.988
Alfalfa	89	10	1.19	1.11

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[1] Large.
[2] Small.

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